

“On the Magnetic Changes of Length in Annealed Rods of Cobalt and Nickel.” By SHELFORD BIDWELL, M.A., Sc.D., F.R.S. Received May 16,—Read June 2, 1904.

The dimensions of a piece of magnetic metal are, in general, changed by magnetisation. When subjected to a longitudinal field gradually increasing from a small value, an ordinary iron wire is at first extended, then, after passing a maximum, it recovers its original length, and finally becomes shorter than when unmagnetised.* In a paper communicated to the Society in 1894† I showed that the changes usually observed were modified if the iron had been annealed. In annealed iron the maximum extension is diminished and contraction begins in a weaker magnetic field; the elongation curve is, in fact, lowered to an extent dependent upon the completeness of the annealing. In the case of a certain soft-iron ring which had been raised to a bright red heat and allowed to cool slowly for about 14 hours, there was no preliminary elongation at all, retraction beginning (just as in nickel) with a very small magnetising force. It is of interest to note that after the lapse of 10 years the ring still retains its peculiar quality; on May 9, 1904 a perceptible diminution of its diameter was observed with a force of no more than 3 C.G.S. units, the diminution, of course, becoming greater with stronger forces. An unannealed ring of the same iron attained its greatest elongation, 33 ten-millionths, in a field of 80, and did not begin to contract until the field reached 420.

In the course of some recent work it became desirable to ascertain whether the changes of length exhibited by magnetised cobalt were analogously affected. Cobalt in the ordinary condition behaves oppositely to iron, contracting in weak fields and lengthening in strong ones. It might be expected, therefore, that if the metal were annealed it would begin to lengthen at an earlier stage of the magnetisation, possibly without any initial contraction. In searching the literature of the subject before undertaking the experiment, I found a very interesting paper by the Japanese physicists Honda and Shimizu entitled “Change in Length of Ferromagnetic Substances under High and Low Temperatures by Magnetisation.”‡ Among the numerous curves given are two showing the changes of length produced by magnetisation in “cast cobalt” and “annealed cobalt” at ordinary temperatures. The curve for “cast cobalt” is of the same character as

* Bidwell, ‘Phil. Trans.’ A, 1888, p. 205.

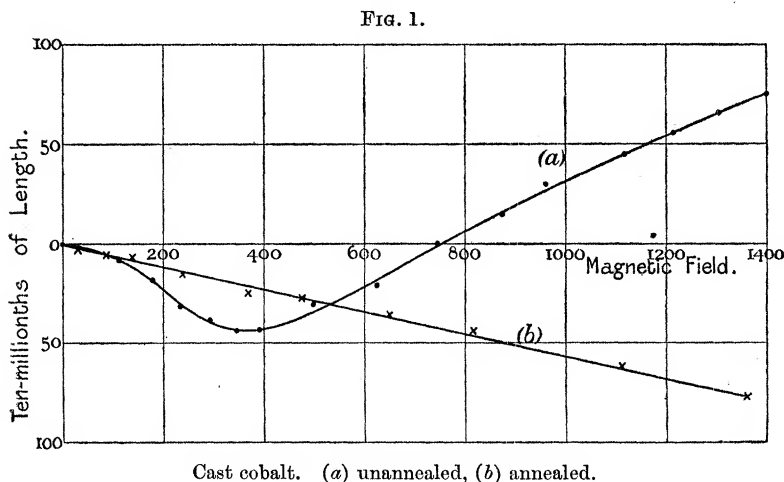
† ‘Proc. Roy. Soc.’ vol. 55, p. 228.

‡ ‘Tōkyō Sugaku-Buturigakkwai Hōkoku,’ No. 19, p. 197. The authors were good enough to send me a copy of the paper in 1903; unfortunately it was not read with the care it deserved until May, 1904.

the one published by myself 16 years ago* (curve (a), fig. 1); that for "annealed cobalt" is an almost straight line, lying, however, not above, but below the axis of H; up to the field of 800 units, at which the experiment was stopped, there is no evidence that the contraction was tending to a limit. The authors make no comment whatever upon this remarkable effect, which may perhaps be well known in Japan, though I have never seen any reference to it in European publications.

The experiments described in the present paper were made with two different samples of cobalt, the one a cast rod, 9 cm. long and 0.56 cm. in diameter, the other a rolled strip, 10 cm. in length, 0.6 cm. in width and 0.08 cm. in thickness. These were enclosed in porcelain tubes, and placed side by side in the middle of a hot fire, not being removed until the fire had died out some 5 or 6 hours later.

In fig. 1, curve (b) shows the result of an experiment with the



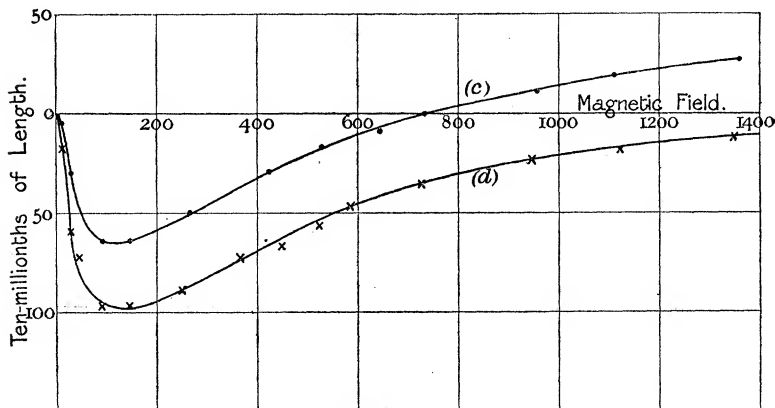
annealed cast cobalt. It will be noticed that the points of observation appear to indicate a slight sinuosity, but hardly greater than might be accounted for by experimental errors; a straight line drawn from the origin to the final point seems to pass evenly enough through the others. The curve agrees well with that given by Honda and Shimizu, and though the field was carried to a much higher value than was reached by them, there is still no sign that the contraction was approaching a limit. Curve (a), fig. 1, shows the changes of length exhibited by another piece of the same cast cobalt when in the unannealed state.

The effect of annealing upon the rolled cobalt was altogether

* 'Phil. Trans.,' *loc. cit.*

different. The behaviour of the unannealed piece is indicated by curve (c), fig. 2; it differs from that of the cast metal chiefly in the fact that the maximum retraction occurs in a much weaker field. The curve (d) for the annealed strip indicates a maximum retraction greater in degree, though it is reached in about the same field. The ascending limbs of

FIG. 2.



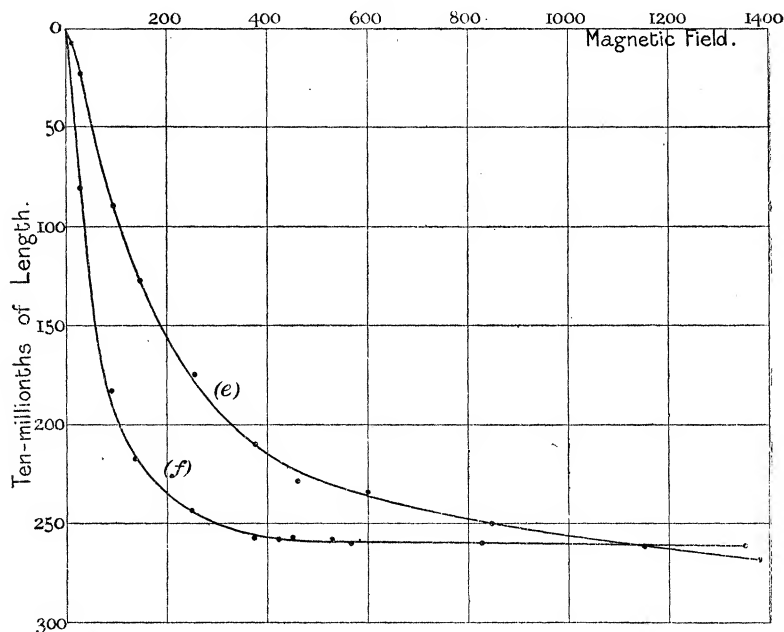
Rolled cobalt. (c) unannealed, (d) annealed.

the two curves are nearly parallel, but it is probable that the curve for the annealed strip would in very strong fields become asymptotic, never meeting the axis of H ; an observation made with a field of 1750, 350 units beyond the limit of the diagram, showed that the retraction was still 9 ten-millionths of the length.

The results of two experiments made with nickel before and after annealing are given in curves (e) and (f), fig. 3. The piece used was a thick wire 9 cm. in length and 0.35 cm. in diameter. After the first series of observations had been made, the wire was annealed in exactly the same manner as the cobalt, and again tested, with the result shown in curve (f). The modification effected in the form of the retraction curve is quite similar to that which annealing produces in the curve of magnetisation, and is probably due to nothing more than increased magnetic susceptibility. No such simple explanation can of course be given of the changes which are brought about in the behaviour of iron and cobalt. The fact that the two nickel curves intersect in a field of 1150 units may be merely an effect of temperature. The magnetic retraction of nickel is, as I have remarked in former papers, sensibly affected by small changes of temperature, and the intersection would be accounted for if the annealed wire happened to be a few degrees warmer than the unannealed.

As a consequence of the reciprocal relation between the changes of

FIG. 3.



Drawn nickel. (e) unannealed, (f) annealed.

length produced by magnetisation, and the changes of magnetisation attending mechanical strain,* it may be inferred that there would be no Villari reversal in well-annealed iron, like that of which the ring above referred to consisted, nor in annealed cast cobalt. In the rolled cobalt, however, to which the curves in fig. 2 relate, it might be expected that the effect would be considerably increased by annealing.

* J. J. Thomson, 'Applications of Dynamics to Physics and Chemistry,' pp. 47—59.